Introducing a population-based outcome measure to evaluate the effect of interventions to reduce catheter-associated urinary tract infection

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Background: The catheter-associated urinary tract infection (CAUTI) measure recommended by the National Healthcare Safety Network (NHSN) accounts for the risk of infection in patients with an indwelling urinary catheter, but might not adequately reflect all efforts aimed to enhance patient safety by reducing urinary catheter use. Methods: We used computer-based Monte Carlo simulation to compare the NHSN-recommended CAUTI rate (CAUTIs per 1,000 catheter-days) with the proposed “population CAUTI rate” (CAUTIs per 10,000 patient-days). We simulated 100 interventions with a wide range of effects on catheter utilization and CAUTI risk in patients with catheters, and then compared the 2 measures before and after intervention across the simulated interventions. Results: Out of our 100 simulated interventions, 93 yielded reductions in CAUTI; however, in 25 (27%) of these 93 simulations, the NHSN CAUTI rate increased after the intervention. In addition, among the 68 simulations in which both the NHSN and the population CAUTI rates decreased, the percent decreases in the population CAUTI rate were consistently greater than those in the NHSN rate. Conclusion: The population CAUTI rate—CAUTIs per 10,000 patient-days—should be calculated along with the NHSN rate, particularly in settings where interventions lead to substantial reductions in catheter placement. We suspect that this population CAUTI rate may eventually emerge as a primary outcome for hospital-based quality improvement interventions for reducing urinary catheter utilization, especially those focusing on avoiding urinary catheter placement.

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performance information. Moreover, the United States Department of Health and Human Services Action Plan to prevent HAIs calls for a 25% reduction in the number of symptomatic CAUTIs per 1,000 urinary catheter-days in the hospital as a national prevention target. Despite this increased focus on CAUTI, however, there are no specific recommendations for how data on CAUTI should be externally reported to consumers or payers, in contrast to specific recommendations provided for reporting of other HAIs. Presently, the most common CAUTI metric used is from the Centers for Disease Control and Prevention’s National Healthcare Safety Network (NHSN). The CAUTI rate used by NHSN is calculated by multiplying the number of CAUTI episodes during a specific period by 1,000 and dividing this number by the total number of indwelling urinary catheter-days during the same period. Although the NHSN CAUTI rate accounts for the risk of infection in patients with an indwelling urinary catheter, it does not account for the risk to the total hospitalized patient population. In addition, it is unclear whether the NHSN CAUTI rate can adequately capture the effect of all interventions to reduce urinary catheter utilization, which are key strategies for preventing CAUTI in hospitalized patients given the frequent use of urinary catheters without appropriate indications. In addition, because the need for a urinary catheter may reflect greater severity of illness, interventions to improve appropriate urinary catheter utilization could even result in a population at higher risk for CAUTI among patients with a urinary catheter. With these issues in mind, we compared the current NHSN CAUTI rate with a population-based CAUTI rate using different simulated scenarios related to potential interventions to reduce catheter utilization, to provide guidance on the most appropriate measure for evaluating CAUTI prevention activities.

METHODS

We developed a computer-based Monte Carlo simulation model of CAUTI to compare the NHSN CAUTI rate and the population CAUTI rate across a wide range of hypothetical interventions. Simulation is an appropriate and effective way of generating data for analysis and performing testing under a large number of possible scenarios, and has been used in many diverse healthcare-related applications. The population CAUTI rate was derived by multiplying the number of CAUTI episodes occurring during a specific period by 10,000 and dividing this number by the total number of patient-days during the same time period (ie, CAUTIs/10,000 patient-days). For each of 100 simulated interventions, 100,000 simulated patients were randomly assigned to be hospitalized before or after intervention, and each of these patients was then assigned 2 underlying probabilities: the probability of having a catheter placed and the probability of acquiring a CAUTI given that a catheter had been placed. Figure 1 shows the structure of the simulation model. Each patient followed one of the 12 paths for each intervention and was assigned a different probability of CAUTI accordingly.

We assumed that the probability of having a catheter placed for any given patient followed a logit model and depended only on whether the patient was hospitalized before or after the intervention. Conservative estimates from previous studies of approaches to reduce urinary catheter utilization have found a preintervention mean catheter duration of approximately five days (range, 5–11 days). As such, we simulated 7 days of total follow-up for each patient, with the duration of catheterization (for those with a catheter) following a discrete uniform distribution ranging from 3 to 7 days. This model implicitly assumes that the probability of catheter placement is constant across time. In the absence of intervention, the probability of catheter placement was assumed to be 0.24, which is the 75th percentile of the catheter utilization ratio in medical inpatient wards reported by the NHSN. We set preintervention utilization at the 75th percentile so that postintervention utilization could vary between the 25th and 75th percentiles, because catheter utilization was not allowed to increase from preintervention to postintervention in our simulation.

We assumed that the probability of CAUTI given catheter placement also followed a logit model, but one that depended on the duration of catheterization as well as whether the patient was hospitalized before or after the intervention. The preintervention risk of CAUTI among those with catheters was assumed to equal 6.7/1,000 catheter-days, the NHSN-reported pooled mean observed in medical inpatient wards. The postintervention CAUTI risk was then allowed to vary between the NHSN 25th and 75th percentiles. Note that CAUTI risk can decrease or increase after intervention, whereas utilization can only decrease or remain constant. Following Garibaldi et al, the risk of CAUTI was assumed to increase by 5% with each additional day that a catheter remained in place.

Simulated interventions were characterized by their effects on the 2 patient-level probabilities. These effects were varied in each round of simulations so as to capture a wide range of potential interventions seen in clinical practice. Specifically, the effect on catheter utilization was allowed to vary between a 57% decrease and no effect, and the effect on the risk of CAUTI in patients with catheters was allowed to vary between a 50% decrease and a 35% increase. These ranges were chosen so as to allow the postintervention probabilities of catheter placement and CAUTI (among those with catheters) to vary between the NHSN-reported 25th and 75th percentiles of the catheter utilization ratio and NHSN CAUTI rate, respectively.

Although an intervention for CAUTI reduction should not directly increase the risk of CAUTI in patients with catheters, our simulation accounted for interventions that could plausibly indirectly increase the measured CAUTI rates. For example, an intervention that reduced catheter placement only among those with the lowest risk of CAUTI would leave only high-risk patients to be catherized, thereby yielding a potential increase in the observed CAUTI rate among catherized patients (even if the intervention directly caused a net decrease in the number of CAUTIs among all patients at risk).

RESULTS

Out of the 100 simulated interventions, 93 yielded reductions in the number of CAUTIs and population CAUTI rate; however, in 25 (27%) of these 93 simulations, the NHSN CAUTI rate increased after the intervention. All but 2 of these 25 simulated interventions led to an increase in CAUTI risk in the patients with catheters, and thus represent interventions that decrease catheter utilization only for those patients who are at low risk for CAUTI (Table 1). Furthermore, in the 68 simulations that led to a reduction in both the NHSN and population CAUTI rates, the population CAUTI rate always decreased to a greater extent than the NHSN rate. (In fact, as shown in the Appendix, this must be the case if utilization does not increase after intervention.) Figure 2 shows the percent change in the population CAUTI (left) and NHSN CAUTI (right) rates, across a wide range of interventions. The 2 effects characterizing the simulated interventions—the effect on catheter utilization and the effect on the CAUTI risk in patients with catheters—are shown on the x- and y-axes, respectively. Thus, each point in each figure corresponds to a different intervention; the color at each point reflects the percent change from preintervention to postintervention in the appropriate measure. Red indicates an increase and blue indicates a decrease; darker reds indicate larger percent increases, whereas darker blues indicate...
larger percent reductions. White indicates no change in the rate. This is akin to a topographic map, in which color reflects changes in elevation.

To compare the performance of the 2 measures, we discuss the simulation results for 3 specific interventions, labeled intervention A, B, and C, each with varying effects on catheter utilization and CAUTI risk among those with catheters.

Intervention A decreases catheter utilization by 53% (x-axis), but increases the risk of CAUTI among those with catheters (y-axis) by 21% (holding duration of catheterization constant). This could correspond to an intervention for which catheter placement and/or utilization is diminished primarily among those who are least susceptible to CAUTI, leaving only those at high risk for CAUTI to be catheterized. In that case, the intervention yields markedly different effects on CAUTI rates from preintervention to post-intervention, with the NHSN CAUTI rate increasing by 20% and the population CAUTI rate decreasing by 36%.

Intervention B decreases the probability of catheter utilization by 38% and decreases the CAUTI risk among patients with catheters by 23%. This intervention lies in the middle range of those we investigated. Here the NHSN CAUTI rate decreases by 26%, whereas the population CAUTI rate decreases by 48%.

Intervention C decreases the probability of catheter utilization by only 9%, but decreases the CAUTI risk among those with catheters by 45%. This could correspond to an intervention that ensures the use of aseptic insertion technique and the use of sterile equipment. For this intervention, both measures display roughly the same behavior, with the NHSN CAUTI rate decreasing by 45% and the population CAUTI rate decreasing by 48%.

The horizontal bands for the NHSN CAUTI rate shown in Figure 2 indicate that the NHSN CAUTI rate provides no information about the effects of interventions on catheter utilization. In particular, the percent change in this measure tracks only the effects on the risk of CAUTI in patients with catheters and is completely insensitive to variation in effects on catheter placement. However, the bands for the population CAUTI rate in Figure 2 are diagonal, indicating that this measure is sensitive to both the utilization and risk of CAUTI. Thus, the population CAUTI rate, which reflects the number of CAUTIs standardized by total population size (rather than the CAUTI rate in those with catheters), is more nuanced with respect to relaying information about the different potential effects of interventions for CAUTI reduction.

### DISCUSSION

To adequately reflect the quality of patient care, measures used to report CAUTI events ideally should capture the effect of quality improvement interventions intended to reduce the use of urinary catheters. This study underscores the importance of the denominator in influencing what an outcome metric is capable of detecting and representing. Our analysis demonstrates that although the NHSN CAUTI rate is a useful and valid metric under certain conditions, it might not always reflect the impact of important quality improvement efforts targeted at reducing inappropriate urinary catheter utilization. Many of the clinical interventions aimed at reducing urinary catheter utilization have focused on removing catheters that are no longer needed or unnecessary rather than on preventing placement. Studies have shown that interventions focusing on removing unnecessary catheters that were already in place led to reduced CAUTI rates and resulted in a lower mean duration of catheter utilization. A study that addressed both avoidance of unnecessary catheter placement and prompt removal of no-longer-needed catheters also reported a lower duration of catheter utilization and fewer infections per 100 cases. Two studies of interventions initiated in the emergency department setting that promoted catheter placement based on...
appropriate indications resulted in placement of fewer catheters, but did not evaluate the impact on CAUTI rates in the hospital setting.\textsuperscript{28,29}

As our analysis suggests, one situation in which the NHSN CAUTI rate might not reflect improvements in health care quality and patient safety is when interventions are used to prevent inappropriate catheter placement. Although this type of intervention may result in a significant reduction in the total number of CAUTIs, the NHSN CAUTI rate may increase after the intervention. Furthermore, our results indicate that the NHSN CAUTI rate may underestimate the effect of certain interventions compared with the population CAUTI rate, even if both measures demonstrate rate reductions. Thus, surveillance efforts using the NHSN CAUTI rate could possibly lead to the erroneous conclusion that an intervention did not improve outcomes, which may affect hospitals adversely in the environment of pay for performance where top performers may be better compensated.\textsuperscript{30} As such, the population CAUTI rate may more accurately reflect the magnitude of improvements in CAUTI prevention stemming from quality improvement and patient safety efforts.

To better evaluate the effect of an intervention on reducing the risk of CAUTIs, we propose the use of a measure that incorporates the risk to all patients receiving care in the hospital. The role of an outcome measure is to accurately reflect the final outcome, in this case the number of CAUTIs. The end goal is to achieve a reduction of total CAUTIs over a specific period for the same population at risk. We suggest using both the NHSN CAUTI rate and the proposed population CAUTI rate, which uses patient-days as the denominator. Measures with patient-days as denominators have been used to evaluate the risk of exposure of health care workers to blood-borne pathogens,\textsuperscript{31} as an incidence rate for methicillin-resistant Staphylococcus aureus infection,\textsuperscript{32} and as an acquisition measure for Clostridium difficile in the hospital setting.\textsuperscript{33} Such denominators include all patients at risk for exposure and the duration of their potential risk, whether or not they are exposed. This more accurately reflects the potential risk, which starts when the patient enters the hospital. Given that every patient without a urinary catheter in place admitted to the hospital is at risk for having a urinary catheter placed, calculating the population CAUTI rate based on patient-days may better reflect interventions that target appropriate placement and prompt removal of catheters that are no longer needed.

Importantly, the population CAUTI rate accounts for both the information contained within the NHSN CAUTI rate and the catheter utilization ratio (Table 2). The current NHSN CAUTI rate is based on the number of CAUTIs compared with the utilization days of the catheters. This measure, in conjunction with the device utilization ratio, may reflect process improvement in the intensive care unit setting, where the majority of catheters placed are initially appropriate and where patients have similar acuity. In addition, collecting data related to device-days is relatively easy in intensive care units because of the high prevalence of device utilization and few units involved. On the other hand, collecting data on catheter-days is cumbersome outside of the critical care setting and labor-intensive unless electronic surveillance is available.\textsuperscript{34} A logistic advantage of the population CAUTI rate is that one of its components (patient-days) is readily available to individual hospitals. Moreover, this rate can be readily calculated from the data currently submitted to NHSN.

Our findings should be interpreted in the context of the assumptions used to develop our simulation model. For example, we assumed that the simulated interventions do not directly affect the duration of catheterization (in patients with a catheter). Simulation models addressing changes in the duration of catheter use may allow for a more comprehensive evaluation of the NHSN CAUTI rate and its relation to the population CAUTI rate. When duration of catheter use is reduced through early removal of catheters that are no longer needed, the NHSN CAUTI rate will vary depending on the risk for patients with a continued need for catheterization. Even if the NHSN CAUTI rate decreases, however, it...
can be shown that the magnitude of this decrease will not match that in the population CAUTI rate, provided that utilization does not increase after intervention (see Appendix).

Furthermore, although in this study we made assumptions regarding the processes of catheter placement and CAUTI development, we are interested primarily in the relationship between the NHSN CAUTI rate and the population CAUTI rate. This relationship is fixed and only partly dependent on the realism of the underlying simulation model. The main limitation of our work is that we only explored the case where the sole difference between the preintervention and postintervention populations is the intervention itself. Thus, when case mix is more than a minor concern, either across hospitals or within a hospital across time, our simulation results may be less relevant.

Importantly, we are suggesting that the population CAUTI rate complements the NHSN CAUTI rate when evaluating hospitals for quality improvement projects aimed at reducing CAUTIs. The population CAUTI rate does not evaluate the risk to those with an indwelling urinary catheter; rather, it reflects the risk of CAUTI in patients in a hospital setting regardless of catheter status. The NHSN CAUTI rate will continue to be the best measure to evaluate the risks associated with any breach of the aseptic process when placing and maintaining a urinary catheter.

Our findings have significant implications on the choice of outcome measures to evaluate the effect of programs to promote appropriate utilization of urinary catheters in the hospital setting. The population CAUTI rate can be particularly useful in evaluating improvement programs within the same institution; on the other hand, the NHSN CAUTI rate is essential for comparing specific units from different facilities, especially in the intensive care setting. As states implement projects to reduce CAUTIs, the concomitant evaluation of both rates using empirical data will provide better guidance on how to best use the 2 measures.

We conclude that both the NHSN CAUTI rate (with catheter-days as the denominator) and the proposed population CAUTI rate (with patient-days as the denominator) are needed to better evaluate the quality improvement processes related to urinary catheter utilization. The NHSN CAUTI rate will continue to be used to evaluate CAUTIs in intensive care or specialty units and to serve as a tool for interhospital comparisons; however, the population CAUTI rate likely better reflects within-institution improvement processes, especially those interventions that promote preventing inappropriate urinary catheter placement.

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References


APPENDIX. Relationship between the change in the population-based rate and the NHSN rate when catheter utilization is reduced or stays the same

Suppose that $P_0$ and $P_1$ are the preintervention and postintervention population CAUTI rates, respectively, and that $N_0$ and $N_1$ are the preintervention and postintervention NHSN CAUTI rates. Then the percent changes in these rates are given by $(P_1 - P_0)/P_0$ and $(N_1 - N_0)/N_0$, respectively.

From Table 2, we have $P_0 = 10 \times N_0 U_0$ and $P_1 = 10 \times N_1 U_1$, where $U_0$ and $U_1$ are the preintervention and postintervention utilization ratios, respectively. If utilization does not increase after intervention (ie, if $U_1 \leq U_0$), then we have

$$\frac{(P_1 - P_0)}{P_0} = \frac{(N_1 U_1 - N_0 U_0)}{N_0 U_0} \leq \frac{(N_1 U_1 - N_0 U_0)}{N_0 U_0} \leq \frac{(N_1 - N_0)}{N_0}$$

Therefore, the percent change in the population CAUTI rate is necessarily less than (or equal to) the percent change in the NHSN CAUTI rate, as long as utilization does not increase after intervention.